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LDRD Final Report (98-ERD-092) Photonic Analog-to-Digital Converter (ADC) Technology

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LDRD Final Report (98-ERD-092)
Photonic Analog-to-Digital Converter (ADC) Technology

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Abstract
We report on an LDRD seed program of novel technology development (started by an FY98 Engineering Tech-base project) that will enable extremely high-fidelity analog-to-digital converters for a variety of national security missions. High speed (10+ GS/s), high precision (10+ bits) ADC technology requires extremely short aperture times (~1ps) with very low jitter requirements (sub 10fs). These fundamental requirements, along with other technological barriers, are difficult to realize with electronics: However, we outline here, a way to achieve these timing apertures using a novel multi-wavelength optoelectronic short-pulse optical source. Our approach uses an optoelectonic feedback scheme with high optical Q to produce an optical pulse train with ultra-low jitter (sub 5fs) and high amplitude stability ($<10^{-10}$). This approach requires low power and can be integrated into an optoelectronic integrated circuit to minimize the size. Under this seed program we have demonstrated that the optical feedback mechanism can be used to generate a high Q resonator. This has reduced the technical risk for further development, making it an attractive candidate for outside funding.

Motivation
Many national security missions, particularly those that are intelligence community- related (IC), involve the application of advanced communication, instrumentation, radar, sensor, and EW systems. These all rely on ADCs to digitize a large information bandwidth (GHz) with high dynamic range and precision. However, the performance of state-of-the-art ADCs has progressed rather slowly, about 1-bit improvement or doubling in sampling speed every 6-8 years. This can, to a large extent, be attributed to limitations of the available semiconductor technologies in terms of device matching, device operating frequencies, and noise and nonlinearity in active devices. To obtain a quantum leap in performance beyond that of current electronic ADCs, we have proposed to develop the enabling technology for a class of photonic ADC architectures based on advanced optoelectronic technology. With the unique ultra-high frequency capability of advanced optoelectronic components, the proposed class of photonic ADCs will simultaneously attain high sampling rates and large dynamic ranges. These photonic ADCs along with advanced sensor technology will allow measurement of physical phenomena of nearly every type with unmatched speed and accuracy. For applications that require high precision, but not necessarily fast effective sample rates, photonic ADCs will enable oversampling at very high sample rates to enable ultra-high precision sigma-delta ADC architectures which trade-off sample rate for precision. In addition to these important IC applications advanced ADC technology such as this will play a major role in next generation prompt instrumentation required to support the Stockpile Management Program at NIF and other experimental venues.

Technical Description
Examination of our basic photonic ADC architecture (Fig. 1) highlights the significance of the proposed optical source development. Our basic ADC photonic front-end (Fig. 1) uses a multi-wavelength ultrashort laser pulse train (sometimes called, a “comb” signal) and a Mach-Zehnder modulator to sample a broadband signal of interest (Fig. 1 RF signal in). The sampled signal is temporally demultiplexed through a wavelength division multiplexer to an array of photo-detectors

where the photodetector outputs can then be digitized by a time interleaved array of slower-speed electronic analog-to-digital converters. While we have envisaged more complex photonic ADC architectures in the course of this study they use the concepts illustrated in fig. 1 and all require the proposed optical comb source to sample a signal of interest.

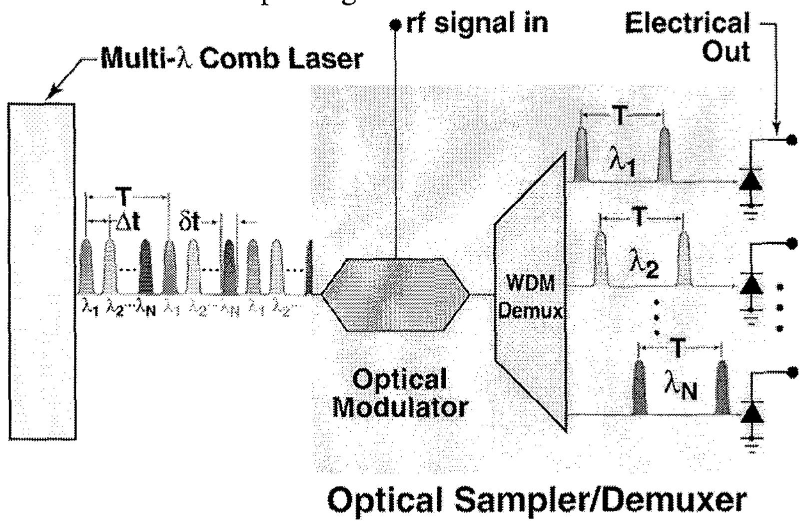

Figure 1. *Photonic front-end building block.*

The multi-wavelength comb laser is realized with a novel externally modulated coupled-cavity Fabry-Perot with optoelectronic feedback (Fig. 2). Here the RF input driving the phase modulator will periodically sweep the optical pass-band through the cw wavelengths, simultaneously pulse modulating each wavelength and providing the appropriate temporal spacing for each wavelength in the resulting comb. A portion of the optical output signal is routed through a fiber delay line back to the phase modulator input, thus creating a high Q optical feedback circuit. The signal is then bandpass filtered optically to select only one wavelength of the multi-spectral pulses for detection. The detected signal is bandpass filtered electrically to eliminate harmonics and amplified with a low noise narrowband RF amplifier prior to driving the phase modulator.

The laser source will generate an optical pulse train with pulse widths between 1-10 ps and a jitter of 1-10 fs. We expect to realize a low jitter optical pulse train with less than 5 fs of jitter over at least a 1 ms integration window using this approach. This jitter specification is at least an order magnitude improvement over state-of-the-art mode-locked semiconductor and fiber lasers. These lasers have relatively large pulse jitter because of the amplified spontaneous emission (ASE) noise present in the lasers. Because we modulate external to the gain medium, and in the absence of ASE, the timing jitter of the our source will be governed exclusively by the effective Q of the optoelectronic circuit and the noise of the RF amplifier driving the external phase modulator. The long term stability will be governed by the mechanical and temperature stability of the electrooptic Fabry-Perot cavity and the fiber feedback loop.

To achieve the required multi-wavelength source of fig. 1, the Fabry-Perot cavity of fig. 2 can be simultaneously seeded with lasers of different wavelengths resulting in a multi-wavelength pulse train. Our approach synthesizes the generation of the required ultra short pulses from an array of continuous wave lasers. Optical pulses have demonstrated pulsewidths as short as 660fs have been demonstrated using this kind of electro-optic synthesis.

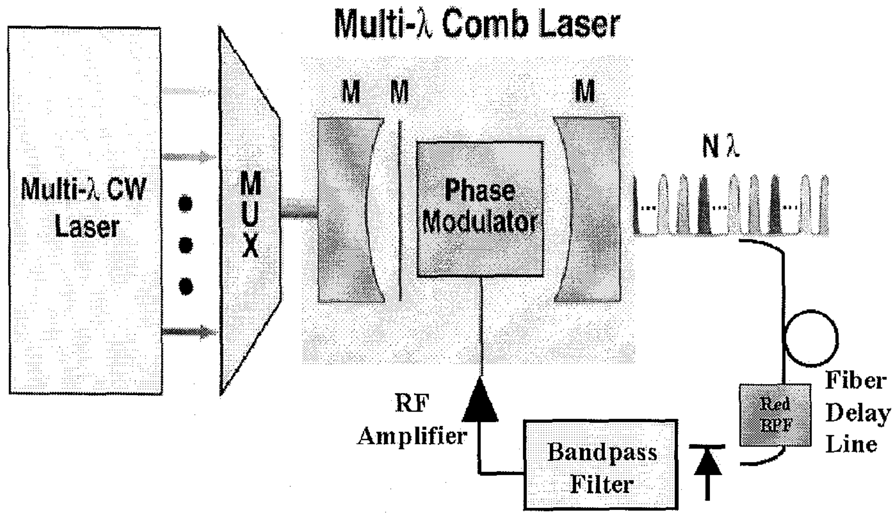

Figure 2. Coupled cavity multi-wavelength comb source with high Q optoelectronic feedback.

Principal Accomplishments

Our strategy with this seed program was to develop the high risk, enabling technology with LDRD funding while pursuing external sponsor funding for prototype systems demonstrations. The high-Q optical-feedback resonator is the key high-risk piece that was developed, in addition to the overall architectural details. We have successfully demonstrated this high-Q optical feedback resonator, illustrated in fig. 1. In figure 1a, a laser operating at 1550 nm is coupled into the Mach-Zehnder modulator optical input. The modulator's RF input port is driven by the modulator's optical output through two optical feedback arms. The amplifiers create enough link gain for the system to break into oscillation. The optical fiber delay lines provide phase locking at integral multiples of round trip time and additional frequency narrowing of the allowed oscillation frequency (thus enhancing the Q). The phase noise of the RF output is shown in figure 1b. These results are very encouraging enabling key progress to our difficult jitter specification.

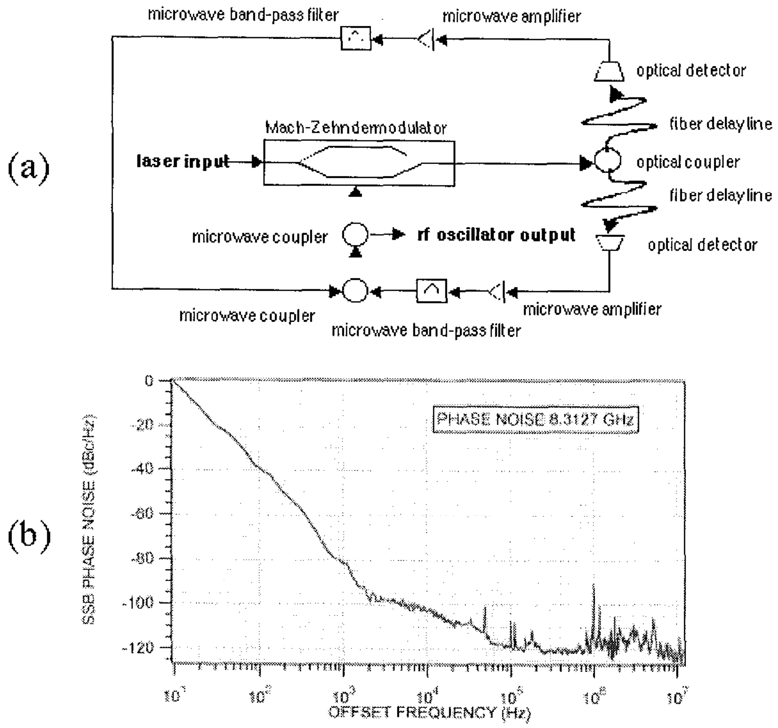

Figure 1. (a) diagram of initial low-phase noise RF driver. (b) phase noise measurement results

In addition this program has achieved the following:

- Several classes of photonic ADC architectures have been conceived. These architectures have many common features including the notion of sampling a signal with a multi-wavelength optical pulse train to allow the signal to be demultiplexed spectrally.

- A novel multiwavelength optoelectronic sampling source have been envisioned. The source develops ultra-short optical pulses using external phase modulation in a Fabry-Perot cavity. This approach enables optical pulse trains to be generated with ultra-low jitter characteristics along with high amplitude stability.

- We have successfully demonstrated the generation of optical pulses from a free-space FP cavity driven by a traveling wave Pockel cell phase modulator using a ring-laser input at 800 nm.

- We designed and procured the integrated optical components necessary to do implement the next phase.

- An external sponsor proposal to continue the development of this work next year has been developed.

Conclusions

The work done thus far under this small LDRD program will position us to develop the remaining component and sub-system technology to enhance ADC system performance beyond that achievable with commercially available components. It is anticipated that this development will be funded by outside sponsors.